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Artificial neural network model of the relationship between *Betula* pollen and meteorological factors in Szczecin (Poland)

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Abstract Birch pollen is one of the main causes of allergy during spring and early summer in northern and central Europe. The aim of this study was to create a forecast model that can accurately predict daily average concentrations of *Betula* sp. pollen grains in the atmosphere of Szczecin, Poland. In order to achieve this, a novel data analysis technique—artificial neural networks (ANN)—was used. Sampling was carried out using a volumetric spore trap of the Hirst design in Szczecin during 2003–2009. Spearman's rank correlation analysis revealed that humidity had a strong negative correlation with *Betula* pollen concentrations. Significant positive correlations were observed for maximum temperature, average temperature, minimum temperature and precipitation. The ANN resulted in multilayer perceptrons 366 8: 2928-7-1:1, time series prediction was of quite high accuracy (SD Ratio between 0.3 and 0.5, $R > 0.85$). Direct comparison of the observed and calculated values confirmed good performance of the model and its ability to recreate most of the variation.

Keywords Birch · Artificial neural network · Meteorological parameter · Forecast model

Introduction

Birch trees (*Betula* sp.) are common throughout Poland. The genus *Betula* belongs to the Fagales order and the Betulaceae family, which also includes *Alnus*, *Corylus* and

Carpinus. Five species of birch present in Poland grow in their natural habitat and a few have been introduced. *Betula pendula* and *Betula pubescens* are the most common and occur most frequently. *Betula pendula* is also often planted in parks, streets and gardens as an ornamental tree. The second species in terms of numbers is the common white birch (*B. pubescens*) which grows in moist habitats like swamp birch forests. The other three species (*Betula humilis*, *Betula nana* 1991, *Betula* × *oycoviensis*) are rare (Seneta 1991; APG II System 2003).

Birch pollen is abundant in the air during April and May, and is a well known major tree-allergen in central and northern Europe (D'Amato and Spieksma 1992) with a significant impact on human health. Estimates suggest that between 10 and 20% of the population of northern and central Europe are allergic to birch pollen (Spieksma 1990). In Poland, according to Rapiejko et al. (2004), patients sensitive to birch pollen first develop symptoms of hay fever when exposed to more than 20 birch pollen grains/m³ air. In Poland, such concentrations of birch pollen occur almost throughout the whole birch pollen season (77–98% of the season). However, atmospheric birch pollen concentrations higher than 155 grains/m³ have been shown to evoke dyspnea (disordered or inadequate breathing), and the number of days with such high birch pollen concentrations make up 20–62% of the total birch pollen season. Although the relationships between atmospheric concentrations of birch pollen and meteorological factors is well documented in literature (Castellano-Méndez et al. 2005; Clot 2001; Corden et al. 2000, 2002; Emberlin et al. 2002; Latałowa et al. 2002; Puc and Wolski 2002; Stach et al. 2008) there are only a few statistical models describing the most important parameters affecting the presence of birch pollen in the air, and their values determining high or low concentrations of birch grains (Castellano-Méndez et al.

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2005; Latałowa et al. 2002). However, the majority of previously proposed models have been aimed more frequently at predicting airborne birch pollen concentrations. One of the reasons for such a situation is the non-normality and non-linearity of variables involved in modelling, when the statistical methods typically used (linear or multiple regression) reveal insufficient performance. Therefore, the use of other modelling techniques should be investigated. One of the methods recently introduced into ecological modelling is the artificial neural network technique (ANN). Neural networks function as a universal approximating system with an ability to learn. This method is especially applicable to multivariate data sets with nonlinear dependencies and does not require variables to fit any theoretical distribution. The main difference between ANN and the programs for algorithmic processing of information, e.g., presented in aerobiological literature, is the ability to generalize knowledge over new, previously unknown data not presented in the process of learning (Carling 1992; Fausett, 1994; Tadeusiewicz 1993, 2001; Osowski 1996; Lek and Guegan 1999). The phenological phase of pollination and the subsequent dispersal of pollen in the air depends on local climatic factors modified by geographical location (Kornaś and Medwecka-Kornaś 2002). These specific relationships are well analyzed and modeled by neural networks. In Poland, ANN techniques have been used hitherto only for fungal spores (Grinn-Gofroń and Strzelczak 2008, 2009) but, because of the differences in the biology of pollen grains and fungal spores, meteorological conditions have different effects on sporulation processes and pollination, and on the means of dispersal of spores and pollen (Shivanna and Rangaswamy 1992).

The aim of this study was to create a forecast model that can accurately predict daily average concentrations of *Betula* sp. pollen grains in the atmosphere of Szczecin using a novel ANN data analysis technique.

Materials and methods

Site information

Szczecin is the capital of Western Pomerania, situated in the Northwest of Poland. The city is surrounded by three woods and hills, and water reservoirs (constituting almost one-quarter of the city's territory). The climate of the region is modified by the influence of Atlantic air masses and the proximity of the Baltic Sea. It has a mild climate, with January the coldest month (-1.1°C) and July the hottest (17.7°C). The average annual temperature is 8.4°C , annual mean relative humidity ranges between 70% and 77%, and rainfall is concentrated mainly in summer. Mean annual

precipitation is 528 mm. The most unfavourable characteristics of the climate of Szczecin include strong and very strong winds, which are frequent especially from November until March (Kozmiński and Czarnańska 1996). Within the city area there are synanthropic plants and trees introduced by man and also primeval forest. The growing season defined as the "period of the year during which growing conditions for native vegetation and cultivated crops are the most favourable" is about 210–220 days. This is the period with a mean 24-h air temperature above 5°C and, in the moderate climate zone in Poland, it lasts from the last spring ground frost to the first autumn ground frost (Kozuchowski and Degrimendzić 2005).

Methods of aerobiological investigation

Aerobiological monitoring was conducted continuously during 2003–2009 using volumetric spore traps of the Hirst design (Hirst 1952) (Lanzoni VPPS-2000, Italy). The trap was set on a rooftop in the Śródmieście district of Szczecin ($53^{\circ}26'26''\text{N}$, $14^{\circ}32'50''\text{E}$), at an elevation of 21 m above ground level. The measuring site was 0.5 km north-west from the Jan Kasprowicz Park, the largest green complex in the part of Szczecin on the left bank of the Odra River. A microscope slide was prepared for each day of measurements. Pollen grains were counted along four longitudinal transects, which were divided into 2 mm (1 hourly) intervals; the daily average pollen concentration was expressed as grains/ m^3 .

Meteorological data

Meteorological data covering the 7 years of study were provided by an Automatic Weather Station (Vaisala MAWS101, Helsinki, Finland) situated in the vicinity of the pollen monitoring site. The meteorological factors considered for assessing the effect of weather conditions on airborne pollen were: mean and maximum wind speed, daily precipitation, relative humidity, mean, minimum and maximum air temperature and the dew point temperature.

Statistical analysis

Due to nonlinearity and non-normality of the analyzed variables, particularly visible in matrix histograms and scatter plots, Spearman's rank correlation analysis was used to examine the relationships between airborne *Betula* pollen concentrations and meteorological variables.

Daily average *Betula* pollen concentrations were modeled using ANNs. Meteorological parameters were used as input variables while the *Betula* pollen concentration was an output variable. ANN modeling was a time series prediction, in which *Betula* pollen content in the 1st year was used as

the additional input. Multilayer perceptrons (MLP) were applied, which mathematically perform a stochastic approximation of multivariate functions (Osowski 1996). Calculations were performed using StatSoft software Statistica 6.1 with an implemented neural network module (Lula 2000; Tadeusiewicz 1993, 2001; Statsoft 2008). The consecutive neural networks were designed and trained using back propagation (Haykin 1994; Fausett 1994; Patterson 1996) and conjugate gradient algorithms (Bishop 1995) by Automatic Problem Solver. Cases were divided randomly into three subsets:

- Training (Tr)—used for training a neural network (70% of cases);
- Verification (Ve)—used for verifying performance of a network during training (15% of cases);
- Testing (Te)—used for assessing predictability and accuracy of a neural model on data not presented during training and validation (15% of cases).

The criteria of choice of the best neural network were: (1) value of SD ratio (ratio between error standard deviation and standard deviation of experimental data), and (2) correlation (Pearson's correlation coefficient between experimental and calculated data).

Special emphasis was placed on sensitivity analysis. Sensitivity analysis creates a ranking of input variables and is based on calculations of the error when a given input variable is removed from the model. The ratio of the error for the complete model to one with the ignored variable is the basis of ordering variables according to their importance.

Variation in the season features analysed in Table 1 was evaluated on the basis of the skewness (the degree of asymmetry of a given distribution about the mean value).

Results

The pollen seasons were relatively short and compact, and the distributions of birch pollen concentrations in individual

seasons were asymmetric and very strongly skewed to the right. The duration of seasons ranged from 23 to 44 days to give an average of 35.1 days. The total amount of birch pollen recorded during the season varied annually. In 2003, the total sum of birch pollen was 19,956 grains, but in 2005 it was only 3,091 grains. In most seasons, the total sum ranged from over 6,000 to 13,000 pollen grains (average about 9,500) (Table 1).

The histogram of *Betula* pollen approximated an exponential distribution. Meteorological parameters seemed to approximate a normal distribution, although the Shapiro-Wilk test confirmed significant deviations from normality (results not shown). Scatter plots indicated non-linear dependencies between *Betula* concentrations and meteorological parameters.

The analysis of Spearman's rank correlations (Table 2) revealed that there was a strong negative correlation between airborne *Betula* pollen concentrations and humidity. Significant positive correlations were observed for maximum temperature, average temperature, minimum temperature and precipitation. Relationships between birch pollen counts and wind speed and dew point temperature were weak and insignificant.

The ANN time series model for raw variables displayed low accuracy ($R < 0.5$, results not shown). The reason was that meteorological variables did not explain a great part of variance in airborne *Betula* pollen concentrations (low Spearman's correlation coefficients) and that *Betula* pollen concentrations often changed rapidly. Therefore, $\text{Log}(x+1)$ transformation of *Betula* content was used to dampen the effect of rapid changes apart from meteorological variables. *Betula* pollen concentrations during the 1st year of the study were used as an additional input in order to substitute information contained in other, not recorded variables.

The MLPs for the ANN were 366 8: 2928-7-1:1, with 2,928 input neurons (8 environmental parameters multiplied by 366 days of the first year studied), 7 hidden neurons and 1 output neuron. The ANN was trained with 100 epochs of back propagation and 23 epochs of conjugate

Table 1 Characterisation of *Betula* pollen seasons. PS 98% total sum of pollen concentration

Year	Feature of season			
	PS (length in days)	Max/date	Total pollen	Skewness
2003	16 April–19 May (34)	5,735/25 April	19,956	4.91195
2004	11 April–16 May (36)	1,373/22 April	9,023	2.81484
2005	5 April–15 May (44)	455/16 April	3,091	2.47119
2006	22 April–20 May (29)	3,390/26 April	12,938	4.51471
2007	1 April–11 May (41)	1,702/15 April	8,389	3.63270
2008	13 April–21 May (39)	1,501/25 April	6,590	4.07476
2009	8–30 April (23)	1,166/15 April	6,088	2.45211
Mean values 2003–2009	10.9 April–14.4 May (35.1)	2,188.8/20.4 April	9,439.3	3.553181

Table 2 Spearman's rank correlation coefficients (P -values) between *Betula* pollen concentration and meteorological variables for all the years considered. * $P < 0.05$

	Mean air temperature	Max. air temperature	Min. air temperature	Dew point temperature	Relative humidity	Mean wind speed	Max. wind speed	Precipitation
<i>Betula</i>	0.17*	0.23*	0.05*	-0.02	-0.41*	-0.02	-0.01	-0.08*

gradient algorithm. The error function used was the sum of squares while the activation function was linear. Time series prediction was of quite high accuracy (SD ratio between 0.3 and 0.5). The root square error for Tr, Ve and Te subsets amounted to 0.07, 0.11 and 0.14, respectively. Direct comparison of the observed and calculated values (Fig. 1) confirmed the good performance of the model obtained and the ability to recreate most of the variation. Only single extreme values of pollen counts were underestimated. This was also confirmed by t-test between recorded and forecasted values, which indicated that there was no significant difference ($P > 0.05$) between predicted and observed values. The Leven's test as well as the Brown-Forsythe test indicated homogeneity of variances.

Sensitivity analysis (Table 3) indicated maximum temperature and humidity as the most important variables in the ANN model, which is consistent with the results of Spearman's correlation analysis. The remaining variables were of lower importance; however, all of them were statistically important in the model (ratio above 1).

Discussion

Betula pollen seasons in Szczecin were similar to those observed at other sites in Northern Europe, e.g. Poland and

the United Kingdom (Corden et al. 2000, 2002). Only the 2009 season in Szczecin was clearly different from the others, in terms of duration (it was the shortest of those examined) and timing (it started and ended in April). This was probably related to the weather: mean daily temperatures throughout April 2009 were $>10^{\circ}\text{C}$ on most days; the maximum daily temperature reached values $>15^{\circ}\text{C}$ and about 70% and rainfall occurred on only 3 days (Kożuchowski and Degrimendzić 2005).

Szczecin is located in a climatic region that is influenced strongly by the Baltic Sea (the climate of the region is modified by the influence of Atlantic air masses). Daily concentrations of birch pollen in the season are high or very high in comparison with the multiannual data from other sites in Poland (i.e., Wrocław, Kraków, Sosnowiec, Lublin and Rzeszów), where the climate is dominated by the continental influences and results in delayed starts of birch pollen seasons and lower airborne birch pollen concentrations (Koźmiński and Czarnecka 1996; Weryszko-Chmielewska 2006). Variability in birch pollen seasons is related to a number of factors, including the resuspension of birch pollen grains; regional and long distance transport of pollen (Szczepanek 1994; Helbig et al. 2004); and biennial rhythms in birch pollen production (Spiessma et al. 1995; Emberlin 1997; Latalowa et al. 2002)

Fig. 1 Comparison of *Betula* pollen time series observed and calculated from a multilayer perceptrons (MLPs) 366 8: 2928-7-1:1 neural network

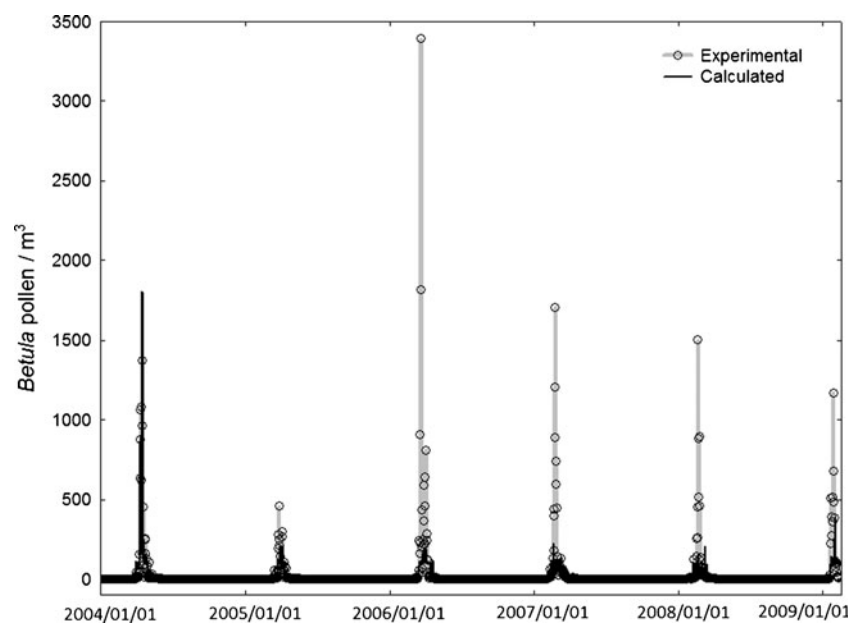


Table 3 Sensitivity analysis of a multi layer perceptron (MLP) s 366 8: 2928-7-1:1 neural network for *Betula* pollen count

	Mean air temperature	Max. air temperature	Min. air temperature	Dew point temperature	Relative humidity	Mean wind speed	Max. wind speed	Precipitation
Ratio	1.87	2.19	1.54	1.69	2.16	1.26	1.14	1.02
Rank	3	1	5	4	2	6	7	8

A number of studies presented in the aerobiological literature have analyzed daily pollen counts (e.g., birch, alder, hazel and grass pollen counts) using different statistical models, e.g., in Argentina (Arizmendi et al. 1993), France (Laaidi 2001), Switzerland (Clot 2001), Germany (Helbig et al. 2004), Spain (Cotos-Yáñez et al. 2004) Italy (Ranzi et al. 2003), Denmark (Skjøth et al. 2008) the United Kingdom and Poland (Corden et al. 2000, 2002; Latałowa et al. 2002). In this study, Spearman's rank correlation analysis shows a statistically significant positive correlation between daily average birch pollen concentrations and three parameters of temperature. This analysis also revealed a statistically significant negative correlation between daily average birch pollen counts and the independent variables relative humidity and precipitation. Similar relationships with temperature, relative humidity and rainfall were also observed by other authors (e.g., Latałowa et al. 2002 ; Méndez et al. 2005; Corden et al. 2002).

The objective of many techniques used for forecasting pollen in the air is to provide accurate information on airborne pollen to sensitive patients in order to help them optimize their treatment process. However, there are comparatively few advanced forecasting models for airborne pollen concentrations. For example, Cotos-Yáñez et al. (2004) presented a short-term prediction of *Betula* pollen levels, with a prediction horizon of 1–3 days starting from the last recorded observations. This model offers great reliability since, by predicting 1 day before, the probability that the model will detect a level equal to or greater than 30 pollen grains/m³ is higher than 90%. In contrast, many other forecasts for daily pollen concentrations often have low predictability. Moreover, a lot of techniques of data analysis are based on assumptions of linearity and normality that often cannot be fulfilled (Lek and Guegan 1999).

ANN needs a single process of learning and shows tolerance to discontinuities, accidental disturbances or even missing data in the teaching set. Thus, the ANN technique can be applied to the problems that cannot be solved in any other effective way, and is particularly suited to predicting the concentration of pollen in the air in relation to weather conditions. Neuron networks are practically able to construct the models needed, making use of the ability to learn from examples (Carling 1992; Fausett, 1994; Lek and Guegan 1999). The neural networks model applied in this

study performed well, and permits generalization of newly introduced pollen concentration data and meteorological conditions not introduced in the process of model construction. Earlier studies on ANN models used in aerobiology (Sánchez-Mesa et al. 2002, 2005) also indicate the reliability of this method based on a series of meteorological data accumulated prior to a given pollen season.

Castellano-Méndez et al. (2005) proposed the use of neural networks as good methods for predicting the probability of threshold values of pollen concentrations, which is information useful to the population suffering from allergy. The model developed using the ANN technique was created to predict the risk level of *Betula* pollen in the air. Moreover, this model does not require variables to fit any theoretical distribution. The paper by Castellano-Méndez et al. (2005) has hitherto been the only one in which ANN was applied to the genus *Betula*. The model proposed in this paper is a continuation of the use of ANN in aerobiology, and its main advantage is that it provides a prognosis for the whole vegetation period. Studying the application of neural networks in time-series forecasting, Ranzi et al. (2003) demonstrated that the relationship between pollen concentrations in the air and meteorological parameters is independent of site in different areas. These authors used ANN to investigate the influence of meteorological conditions on the timing of the beginning of the pollen season. The authors also suggested that including the greatest possible number of parameters with a potential impact on the concentration of pollen in the air would produce reliable forecasts. The forecast obtained by the ANN method refers to the whole time series, including the period prior to pollen appearance in the air, not only at the beginning of the season, or the appearance of the threshold values. Arizmendi et al. (1993) showed that a neural network, trained with measured values of pollen concentrations, was able to predict near future values. However, without the environmental parameters used in their approach, it was impossible to predict the start of the pollen season. This method could be used only after the beginning of the season, which was a serious drawback. The ANN technique applied to *Betula* in this study eliminates this drawback as the method can be used at any moment of time and provides a forecast for the beginning, course and the end of the pollen season using only meteorological parameters.

In this model, maximum temperature and humidity proved to be the most important variables. The remaining parameters were of lower importance but all were statistically important in the created model (ratio above 1). A comparison was made of the ordering of meteorological factors according to their statistical importance obtained from the ANN parametric sensitivity analysis and Spearman's correlation. Maximum temperature and relative humidity had the highest rank according to both methods (in Spearman's correlation the order is reversed). The third position according to both methods was taken by mean air temperature. At the fourth position according to the ANN sensitivity analysis there was dew point and minimum temperature, and, according to Spearman's correlation, precipitation and also minimum temperature. In this comparison, the fourth position in terms of statistical importance, i.e., precipitation and dew point (ratio 1.69) is interesting. It is known that, as a result of hydration, pollen grains break open and release allergens of birch directly to the air (Grote et al. 2001), and this process intensifies immediately before rainfall, at the dew point temperature. Therefore, it is important to take this meteorological variable into account in analyses of correlations with pollen concentrations (Kasprzyk 2008).

Conclusion

This study indicates the possibility of predict airborne *Betula* pollen concentrations from meteorological conditions by using a neural network time series model. The only requirement is to use pollen data from the preceding year.

The most important meteorological conditions with respect to predicting birch pollen season parameters were maximum air temperature and relative humidity. These two variables considerably affect the release and dispersal of birch pollen. The ANN technique offers possibilities for forecasting daily birch pollen concentrations and characteristics of the birch pollen season and, consequently, this method should be considered in Poland and in other parts of Europe.

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